Knee Surg Sports Traumatol Arthrosc
DOI 10.1007/s00167-014-3173-4
Knee

The position of the tibia tubercle in 0°–90° flexion: comparing patients with patella dislocation to healthy volunteers

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Abstract:

Purpose: The aim of this study was to measure the tibia tubercle trochlea groove distance (TT-TG) as a function of knee flexion. Our hypothesis was that there is a different pattern in healthy volunteers and patients with patella instability (PFI).

Methods: Thirty-six knees of thirty patients with at least one dislocation of the patella and thirty knees of thirty healthy volunteers as control group were analyzed with magnetic resonance (MR) imaging by three different observers. The TT-TG was measured in steps of 15° between 0° to 90° of knee flexion. Furthermore, the alignment of the leg (MA), the femur torsion (FTor) and the tibia torsion (TTor) were calculated.

Results: The TT-TG was higher in patients compared to volunteers and in extension compared to flexion. This difference was statistically significant ($p<0.05$). Most of the patients with a TT-TG above 20 mm in extension showed a high decrease in flexion to normal values. In some patients this compensating mechanism fails. MA, FTor and TTor were not different in patients and control group (n.s.).

Conclusion: The TT–TG distance is dynamic and decreased significantly during flexion in knees with PFI and healthy volunteers. However, there were a small number of patients in the PFI group where this compensation mechanism did not work. Therefore, the decision to perform a tibia tubercle osteotomy should not be based on one single measurement in extension or 30° of knee flexion.

Level of Evidence: Level II

Keywords: TT–TG distance, Patella, Patellar instability, Distal malalignment, Dynamic MRI

Introduction

The distance between the tibial tuberosity and the trochlear groove (TT–TG) is a widely used parameter for patellofemoral instability (PFI). A distance more than 20 mm is generally regarded as threshold between normal and pathological findings [4]. MR-imaging can be used with the same accuracy than CT techniques to measure the TT-TG distance [17]. Nevertheless the TT-TG has certain limitations and therefore should not be used as a single parameter for decision making in patients with PFI [3, 20]. One of the major disadvantages is the static measurement of a complex dynamic articulation in either full extension or 30° of flexion only [5]. Some recent papers described that during flexion the TT-TG decreases, but the dynamics and clinical relevance of this finding for patients with PFI remains still unclear [9]. To the best of our knowledge this is the first study to analyze the normal dynamic pathway of the TT-TG as a function of knee flexion and compare it to the pathological dynamic conditions in patients with PFI. Our first hypothesis was that there is a difference between the TT-TG in full extension and different flexion angles for both groups. The second hypothesis was that patients with PFI show a different dynamic pattern when compared to healthy controls.

Material and Methods

Magnetic resonance scans of the knee joints of two groups (patients with PFI and volunteers) were analyzed and data collection was performed retrospectively. The PFI group comprised 30 patients (36 knee joints) with at least one episode of lateral patella dislocation. This was proven by history, clinical examination and imaging findings by the first and senior author. The patients were recruited from a consecutive series of patients with lateral patella dislocation at one institution. Patients with prior surgical patella realignment procedures were excluded. The volunteer group comprised 30 healthy volunteers (30 knee joints) with no history of injury, knee surgery or pain in the lower extremity. There was no significant difference in age and sex distribution between the two groups. The mean age was 20.5 years (range, 12–37 years) versus 23.1 years (range, 17–47 years) and there were 87 versus 77% females for PFI patients and volunteers respectively.

The MR scans were performed on an open 1.0-Tesla MRI unit (Philips, Eindhoven, Netherlands) using proton-density-weighted turbo-spin-echo sequences (TE 30 ms / TR 5000 ms, field of view 190 mm, slice thickness 4 mm, flip angle 90° and image matrix 292 × 180 pixels). The participants were positioned laterally with the leg fixed in a MRI knee positioning device (MP Flex-M coil - Philips, Eindhoven, Netherlands), which contains a scale for the different knee flexion angles. The pelvis and the foot were fixed in neutral position with two Velcro straps and the thigh and lower leg rested on a plate. Finally, all participants were placed in the supine position with the hip and knee joints extended to 0°. The feet and knee joints were fastened to avoid any movement. Serial images were taken from the hip, knee, and ankle for evaluation of the torsion [6, 21] and axis [18] of the leg.

Image analysis was performed by the first author and a board-certified radiologist, each with 6 years of MR experience, and a board-certified general practitioner with little MR experience. MR images were presented randomly and investigators were blinded to patients' data and study group. The measurements on the MR images were performed by each individual reader using the ViewForum workstation (Philips, Eindhoven, Netherlands). One month later, the primary author read all MR studies a second time.

The TT–TG distance was defined as the mediolateral distance between the intersection point of the center of the tibial tubercle and the deepest bony point of the proximal trochlear groove [17]. The transepicondylar axis was selected as posterior reference line for all flexion angles, since the posterior condylar line can not be used for measurements in deeper flexion. The TT–TG distance was measured from 0° to 90° flexion in 15° increments. The linear trend line (α angle) corresponded to the amount of change per degree of TT–TG while the knee was bent (Fig. 1) and was calculated for each participant.

In an additional analysis all patients were separated into the two subgroups with normal TT-TG up to 15mm (subgroup A) and pathological TT-TG 20mm or more (subgroup B). On the MRI torsional profile images of the hip, knee and ankle the torsion of the femur (FTor), torsion of tibia (TTor) [16] and the mechanical axis (MA: positive values = varus, negative values = valgus) of the involved leg [10]) were included in the analysis.

Institutional review board approval was obtained (Medical University Graz, IRB 00002556) and all participants gave written informed consent.

Statistical analysis

Data were analysed using Minitab 15 software (Minitab Inc., State College, PA). Sample size calculation (ρ=0.5, α=0.05) showed a Power of 0.90 for 28 knees in each group. Statistical differences among the different flexion angles were determined using balanced one-way analysis of variance with seven factors (the seven flexion angles). To identify the angles with statistical difference a t-test with Bonferroni correction was performed [2]. For each flexion angle, an unpaired t-test was performed to check for a statistically significant difference between the PFI patient and volunteer groups. The slope differences (alpha angle) of the linear trend lines of PFI patients and healthy volunteers were investigated using a paired t-test. For each of the flexion angles the intraclass correlation coefficient (ICC) for multiple measurements by different observers was evaluated.

Results

The main results are summarized in Table 1 and Fi. 2. The overall TT-TG distance for all patients showed a constant and significant ($p < 0.05$) decrease from 0 to 90° of flexion. Healthy volunteers showed a significantly ($p < 0.05$) shorter TT–TG distance for each knee flexion position compared to PFI patients. There was a constant decrease of the TT-TG during flexion for all measurements in both groups with the exception of volunteers between 15° and 30° and PFI patients between 30° and 45°. The amount of change (alpha angle) in the TT–TG distance during flexion was not statistically different between PFI patients (mean alpha slope −3.8, SD, 5.6) and volunteers (mean alpha slope −2.1, SD, 2.8).

The analysis of the two TT-TG subgroups showed that 20 volunteers (66 %) were in subgroup A with a normal TT-TG and 10 (33%) were borderline (16-19mm). From the PFI patients 10 knees (28%) showed a normal, 14 knees (39%) a borderline (16-19 mm) and 12 knees (33%) a pathological TT-TG. For further evaluations the 24 borderline cases were excluded. The TT-TG changes during flexion between the two subgroups revealed a completely different pattern. In subgroup A, the change in the TT–TG distance was low during flexion from mean 10mm (SD 4mm) to mean 8mm (SD 4mm) at 0° and 90° of flexion respectively. In Group B the mean TT-TG showed a significant decrease from mean 23mm (SD 4mm) to mean 14mm (SD 11mm) from full extension to 90° of flexion. Ten of the 12 knees with pathological TT-TG showed this substantial decrease in the TT–TG distance during deep flexion (Fig. 3a–c). Two knees showed a completely different pattern with continuous high TT-TG values or even an increase during flexion with a complete decompensation of the TT-TG.

The mechanical leg axis (MA) and torsion of femur and tibia bones, (FTor, and TTor) were not different both between PFI patients and volunteers (n.s.) and between TT-TG subgroups A and B (n.s.).

Inter- and intraobserver agreement and reliability were excellent with an ICC for all defined TT–TG distances between 0.85 to 0.93.

Discussion

The most important finding of the present study was that the TT-TG distance showed a constant and significant reduction from 0° to 90° of flexion for both groups confirming our first hypothesis. Comparing the PFI group with the healthy volunteers the TT–TG distance was significantly higher during all flexion angles in the patient group. The amount of TT–TG decrease (alpha angle) was not statistically different between PFI patients and healthy volunteers. Both groups showed a common dynamic pattern of TT-TG decrease during flexion, which does not confirm our second hypothesis.

The TT–TG distance is an important factor for PFI. There is a general agreement that surgical realignment procedures are indicated in patients with a TT-TG exceeding 20mm [20]. Nevertheless the TT-TG has some disadvantages. First the distance cannot differentiate where the deformity is (tibia, femur or both). It was shown, that some patients with a pathological TT-TG have a normal position of the tibia tubercle [18]. Correcting the deformity at the wrong side might create another new deformity. This theory is supported by the findings of Kuroda et al. [12] and Mani et al. [13], who found an alteration in the tibiofemoral kinematics after medialization of the tibial tuberosity in some cases. Second the routine TT-TG is measured in extension [19]. However most patella dislocations occur around 30° of flexion. . Third the patellofemoral articulation represents a very dynamic joint and is guided by different bony and soft tissue structures. It was already observed that the TT-TG decreases during flexion [9] but the clinical significance and biomechanical pathway of this pattern was not well understood so far.

The first finding of this study showed that the TT–TG distance significantly decreased during all flexion angles for both groups (Table 1 and Fig. 2). This corresponds to previous findings in the recent literature. Izadpanah et al [9] described a decrease in the TT–TG distance from extension to 30° of flexion without muscle contraction. Nagamine et al. [14] found a decrease in tibial tubercle lateralization at 30° flexion and Yamada et al. [22] described a shorter distance between the patella and tibial tubercle at 50° flexion compared to full extension. The new finding in our study was that this decrease was nearly constant for all flexion angles in both groups. This common biomechanical pattern can be explained by the fact that once the patella comes into contact with the trochlea the pathway is guided along the trochlea groove (motion guided by conformity and constraint) [8]. Furthermore the unlocking of the screw home mechanism of the knee in early flexion allows the tibia tubercle to follow the tension of the extensor mechanism rotating the tibia tubercle under the trochlea (Fig 3 a-c). Nevertheless the recommendation for distal patella realignment procedures to align the tibia tubercle to the trochlea groove in 90° of knee flexion [11] could not be confirmed in our healthy volunteers group. The TT-TG in 90° was still positive with a mean of 8 mm.

The second outcome of this study that the PFI group showed significantly higher TT-TG values in extension and 30° of flexion compared with the volunteers was already well described in literature [7]. The new finding in this study was that this difference in the TT-TG distance continues for all flexion angles and the PFI group never reached the values of healthy volunteers. Interestingly the amount of changes in the TT–TG distance during flexion (alpha angle) was not different between PFI patients and volunteers.

Static bony factors including mechanical axis (MA), torsion of the femur and tibia (Ftor and Ttor) had no influence on the TT–TG distance during flexion.

Some interesting observations could be made, when analyzing the subgroups of patients with normal or pathological TT-TG. Not all PFI knees had a pathological TT-TG. This had been already described in the literature [7]. Furthermore the knees of subgroup A (normal TT-TG) had significant less changes during flexion when compared to subgroup B (pathological TT-TG). This might be explained by the fact, that the patella was nearly centered above the trochlear groove in extension already and needed only little movement between the trochlea and the tibial tubercle during flexion in subgroup A. In contrast in subgroup B the patella is significantly positioned lateral to the trochlear groove in extension. TT-TG distance significantly decreases during flexion once the patella is guided by the trochlea groove (Fig. 3a-c).

Probably, the most interesting finding of this study was that there were two outliers in the PFI group. For these patients the TT–TG distance remained high or even decompensated during flexion. The reasons for this decompensation might be multifactorial and have to be examined in more detail in future studies. With the current knowledge, these outliers should be regarded to have a complex maltracking, which cannot be corrected by a single distal realignment procedure. In these severe cases, the only solution might be a combination of different soft tissue and bony corrections to realign the patella.

The strength of this study was that the measurement of the TT–TG distance at different degrees of knee flexion showed excellent inter- and intraobserver agreement ($\kappa > 0.75$) although the evaluations were performed while blinded to patients' data and study group.

Nevertheless, there are some limitations of this study. (1) The originally described reference axis (posterior condylar line) was changed to the transepicondylar axis because the measurements were performed until 90° of flexion. However, this seems to have no impact on the outcome based on the comparison of the TT–TG distance of healthy volunteers in this study (mean 12 mm; standard deviation 5 mm) with that in other publications [7]. (2) MR imaging was performed without muscle contraction. There is consensus in literature that the position of the patella changes with contraction of the extensor mechanism [1, 15]. However, this effect seems to be less important in deeper flexion [9]. (3) The participants were positioned laterally, with the thigh and lower leg in one plane and the foot in neutral position. This is different from the position of the leg during gait and most other activities. (4) The subgroup B (12 knees) was highly underpowered. Nevertheless, a statistically significant higher decrease of the TT-TG compared to subgroup A could be shown.

Not all patients with a pathological TT-TG followed the same pattern in flexion. Therefore, the decision to perform a tibia tubercle osteotomy should not be based on one single measurement in extension or 30° of knee flexion.

Conclusions

This study showed that the TT–TG distance is dynamic and decreased significantly during flexion in knees with PFI and healthy volunteers. Once the patella is centered in the trochlear groove, the tibial tubercle follows the patella and leads to a decrease in the TT–TG distance. There was no difference in this constant compensation mechanism during flexion for both groups. However there were a small number of patients in the PFI group where this compensation mechanism did not work.

Conflict of interest

The authors declare that they have no conflict of interest.

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Figures

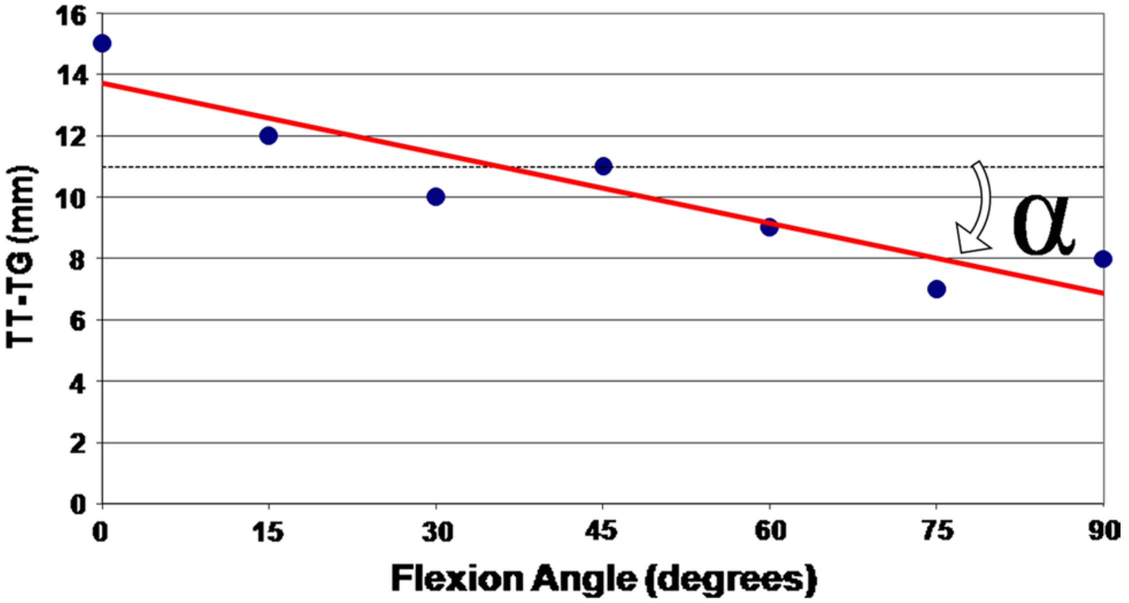

Fig. 1 Slope of the linear trend line. Blue dot = TT–TG distance at different flexion angles, red line = linear trend line, α = slope of the linear trend line

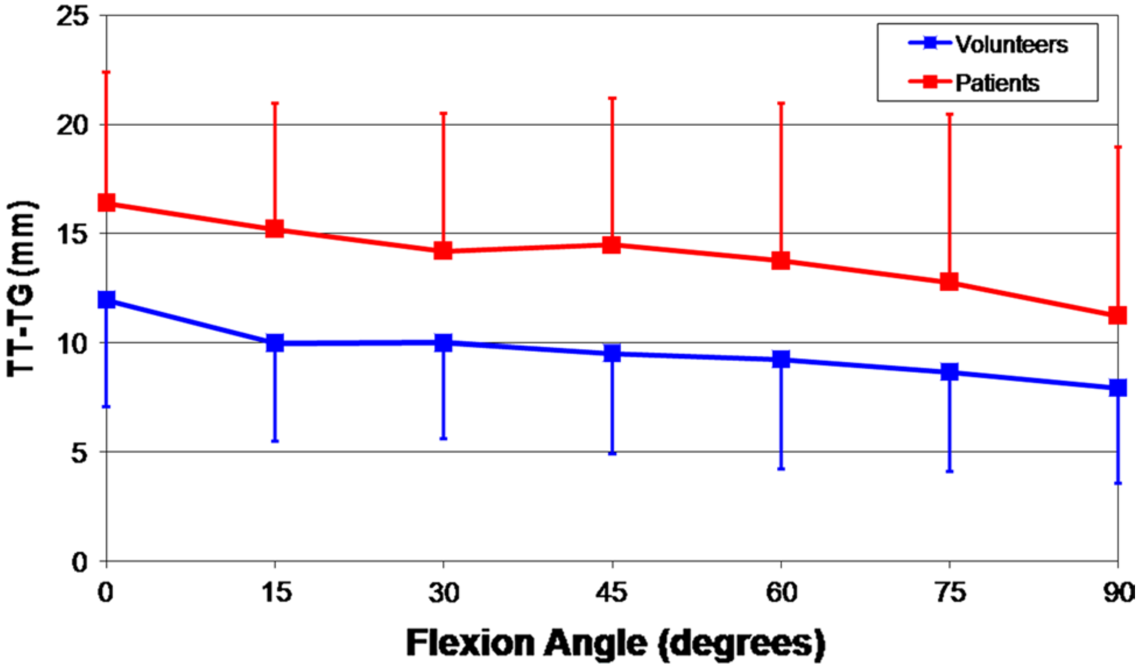

Fig. 2 TT–TG distance of patients and healthy volunteers at different flexion degrees. Red = patients, blue = healthy volunteers, ■ = mean value

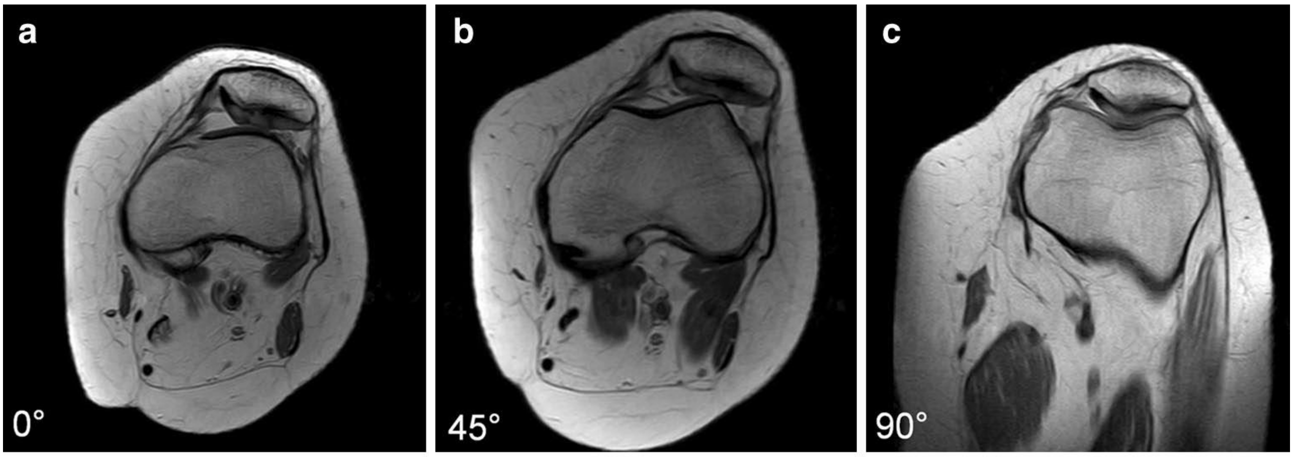

Fig. 3 MRI of a patient with lateralization of the patella in extension. The TT–TG decreases during flexion. Once the TT–TG is <15 mm, the patella begins centering. **(a)** 0°: TT–TG = 23 mm, **(b)** 45°: TT–TG = 22 mm, **(c)** 90°: TT–TG = 3 mm

Table 1 Table of all TT-TG measurements

Flexion angle	TT–TG in mm					
	All participants		Healthy volunteers		Patients	
	Mean	SD	Mean	SD	Mean	SD
0°	14	6	12	5	16	6
15°	13	6	10	4	15	6
30°	12	6	10	4	14	6
45°	12	6	10	5	14	7
60°	12	6	9	5	14	7
75°	11	6	9	5	13	8
90°	10	6	8	4	11	8

Flexion angle	TT–TG <15 mm		TT–TG >20 mm		Varus knees		Valgus knees	
					TT–TG in mm		TT–TG in mm	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0°	10	3	23	4	15	5	13	6
15°	9	4	18	9	12	4	11	6
30°	10	4	18	9	12	4	11	5
45°	10	4	17	9	12	4	12	6
60°	10	5	17	9	11	5	11	5
75°	9	4	16	10	10	5	9	4
90°	8	4	14	11	10	5	9	4

MD mean value, *SD* standard deviation